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Array Sizing Pattern and Rated Power Operation of Solar Pumps in India

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ABSTRACT

In India solar irrigation pumps are installed under a fixed scheme of operating solar array and the capacity of a pump. However, the variation in instantaneous radiation over a day and in different months varied the input power. Therefore, it is always desirable to operate the pump at its rated power for a longer duration to get high operating efficiency water yield efficiency. This provides good irrigation coverage area under pressured as well as conventional flood irrigation method. This paper presents an assessment of one of the most preferred solar irrigation pumps in India, i.e., the 3 hp solar pump operated by a 3.0 kWp fixed solar array. Study further showed that the rated power operation of this system persists only for few hours compared to the available sunshine hours on a day, and for the rated power operation the irradiance should be in the neighbourhood of 0.7 kW/m2. Hence, the current pattern of array sizing is supposed to be inappropriate.

Keywords: Solar Radiation, Irrigation Pump, Smallholders, Pressurised Irrigation, Solar Array

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INTRODUCTION

Lack of requisite surface water supply mechanism, erratic rainfall, and long dry spells are making the agricultural operations more energy intensive. The trend has also aggravated the groundwater abstraction for irrigation purpose, as there are about 30 million groundwater extraction structures exist in India of which about 10 million runs on diesel (Phillipe, 2014; MIC, 2018). Despite intensive electrification, most of the agricultural farms are still not connected with grid lines (Ray and Pullabhotla, 2023), and those connected are suffered by frequent power cut and voltage fluctuations (Obafemi et al., 2022). The continuous increase in fuel prices has further decreased the irrigation affordability, particularly for smallholders and posing challenges to food and nutritional security of the nation (Kalamkar et al., 2015). A low carbon emission obligation on the government led the promotion of solar energy use in agriculture (MoEFCC, 2022). The ministry of new and renewable energy (MNRE) has targeted to install 1.75 million standalone solar agriculture pumps and the solarization 1.0 million existing diesel pumps by 2026 under the subsidy schemes (Yashodha et al., 2021)

Further, the solar irrigation pumps are provided under a fixed scheme of solar array size and the operating pump capacity (MNRE, 2019). The technical brochure of solar system contains information only about the discharge on daily basis and nothing is revealed about the duration of rated power operation of the pump. However, this information is critical while operating pressurised irrigation system with this solar pumping system, as a static discharge controls the volume of irrigation and pushes the waterfronts on soil surface more rapidly. This minimises deep percolation losses and improves irrigation efficiency (Rahman and Singh, 2014)

In India, out of 146.5 million agricultural farms about 85.9% farms are small with operational size ≤2.0 ha (Agriculture Census, 2015-16). Hence, the most preferred solar irrigation system among smallholders is 3 hp solar pump operated by 3.0 kWp solar array. This paper presents the assessment of this solar system for rated power operation over a day in different moths to assess the appropriateness of this array sizing under the prevailing solar radiation condition in India.

MATERIALS AND METHODS

This study was conducted at Bhagwatipur village (26.28 N, 86.05 E) of Madhubani district of Bihar. The characteristics parameters of the system, used in this study, are reported in Table 1. A submersible pump was used in this solar groundwater pumping system. The operating motor was an induction motor, operated under three-phase input power arrangement. The array was manually tracked by under dual axis tracking mechanism.

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Table 1: Specifications of solar system components and combination characteristics

Electrical Parameters of solar module		Electrical characteristics of pump and VFD	
Type of Module	Polycrystalline	Motor rating	2150 W
Power (Pmax)	300Wp ± 3%	Operating array size	3000 Wp
Open circuit voltage	44.64 V	Modules combination	All in series
Short Circuit Current (ISC)	8.75 A	Inverter /controller	VFD
Current at Maximum Power (IMP)	8.35 A	Power supply arrangement	3-wire, VFD-Pump
Voltage at Maximum Power (VMP)	35.93 V	Phase arrangement	1200
Temp coefficient of Power	± 0.4% / °C	Phase voltage	220 V (AC)
Module efficiency	15.4%	VFD efficiency	97.3%

RESULTS AND DISCUSSION

In general, the output voltage from a solar array remains unchanged, but it could vary with sunlight intensity as cell voltage remains constant as longer as there was sufficient sunlight. As sunlight intensity increases more photons strike the solar cells and generating more electron-hole pairs. This increases the output current. The dc output voltage from the array, VDC, was measured by a voltmeter equipped with a data logger. The data was recorded at an interval of 1s, and data-logger was in tune of International Time Standard. The VDC vs. time graph of the solar system is shown in Fig. 1. The time scale was not as usual but it adequately representing the case for interpretation. The Fig. 1 shows that the VDC was usually high and fluctuating during early morning and evening but stabilises about around 350V when there was an appreciable amount solar radiation on the array. At the extremity of the day, the Vdc was maximum and was equal to 425 V. This much high voltage was due to maximum open circuit dc voltage VDCO under minimum reverse saturation current ISC. This ISC was produced by recombination of charge carriers under reverse bias which was not only because of the visible light but also due to some thermal radiation and therefore ISC was available even in absence of visible light. Further, at this point the peaks and valleys in VDC were due to the sensitivity of recombination phenomenon of charge carriers to the thermal agitation, as a minute change in exciting radiation leads a considerable change in ISC and also in VDCO (Zekry et al., 2018). Once an appreciable amount of solar radiation was available, the saturation current ISC reached to its maximum value and then overcome by the forward current IDC. This reduced the VDC to a static value and remained as such till an appreciable amount of solar radiation was available. As day advanced, the forward load current IDC succeeded and VFD convert VDC into a three-phase ac voltage.

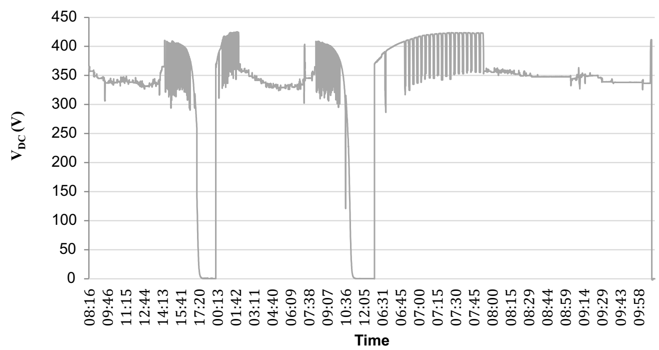

Fig. 1: Variation of VDC over daytime on a bright day

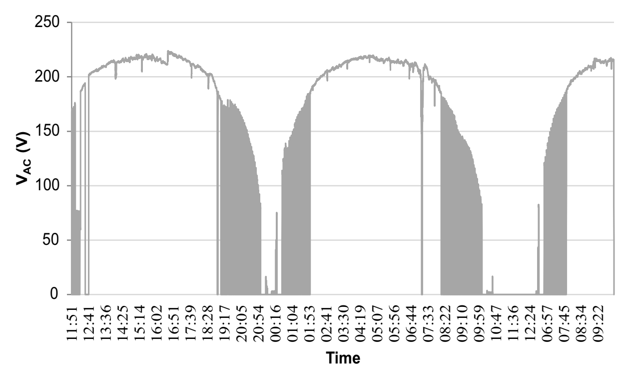

Fig. 2: AC voltage output from VFD in a phase on a bright day

The ac output voltage VAC in each phase was measured by an ac voltmeter equipped with a data logger. The variation of VAC in one phase against the time is shown in Fig. 2. The VAC was nearly 220 V. Often there were sudden drops in VAC, but it was either due to a sudden change in radiation intensity or due to mismatch of some sensitive internal circuit elements. The corresponding ac output current IAC was plotted against the time (Fig. 3). The IAC varied with radiation intensity and the corresponding power PAC run the pump. With the assumption that the power factor circuit is 1, the P_{AC} was equal to $\sqrt{3}V_{AC}I_{AC}$ 12 (Fleckenstein, 2016). However, for rated power operation the input power should be 2.2 kW for which IAC must be at least 5.7 A. The measurements for VDC, VAC, IAC were performed in the month of April on a bright day. The Fig. 3 showed that in this month the maximum current IAC was about 6.6 A for about 5 hours, i.e., above the threshold value of 5.7 A for rated power operation.

The global solar radiation of the site was measured by a pyranometer and the mean monthly averaged daily instantaneous solar radiation intensity during April was in the range of 200 - 930 W/m2. The minimum limit was set at 200 W/m2, as conventionally it was good to take this instead of 0.0 W/m2 (Ramchandra et al., 2011). Further, the characteristics relationship between the current of a module I'DC and the load voltage of the module V'DC at different radiation intensity is shown in Fig. 4. As all the modules of array were in series and net current from the array IAC was almost equal to I'DC. The interpretation of the plot showed that at instantaneous solar radiation 700 W/m2, the IAC was nearly 6.0 A. This shows that the limiting value of instantaneous radiation intensity on solar array for rated power operation was 0.7 kW/m2.

To assess the period rated operation over a day, the mean monthly instantaneous solar radiation of the site for different months was plotted against the cutoff value of 0.7 kW/m2 (Fig. 5). The intersection of curves with time axis gave the duration of rated power operation on a bright day of different months. From this plot it was observed that from March to October on bright day the pump was running at rated power only for few hours and over a major part of sunshine period it run below its rated power. From Nov to Feb, it never achieved its rated power point. The duration of rated power operation for different months against the total sunshine hours over a day is shown in Fig. 6. In the month of October, the duration of rated power operation was minimum and equal to 2.10 h and maximum duration of 5.17 h was in the month of April.

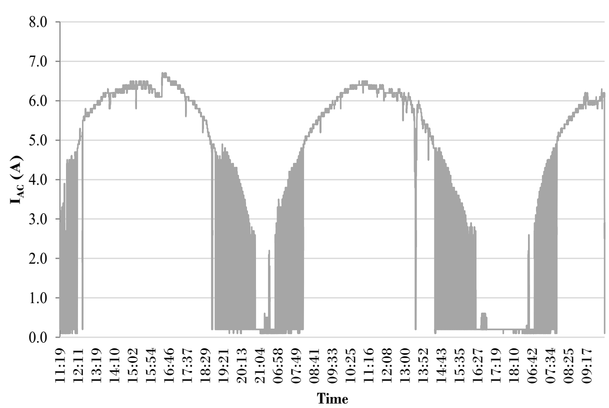

Fig. 3: IAC output from the drive on a bright day

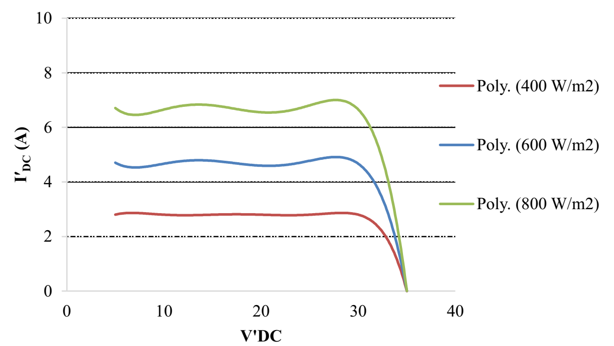

Fig. 4: V-I characteristics of 300 Wp solar module under instantaneous solar radiation

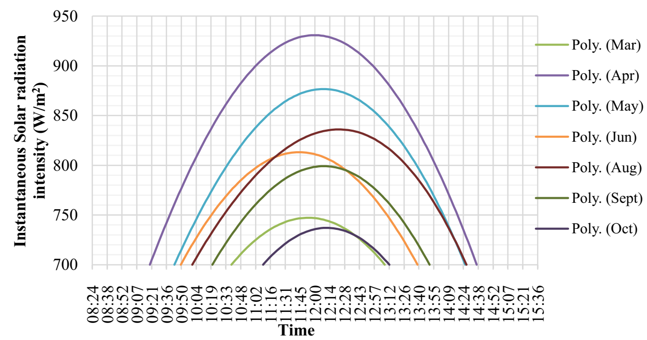

Fig. 5: Instantaneous solar radiation Intensity on a bright day for different months with cut off value 700 W/m2

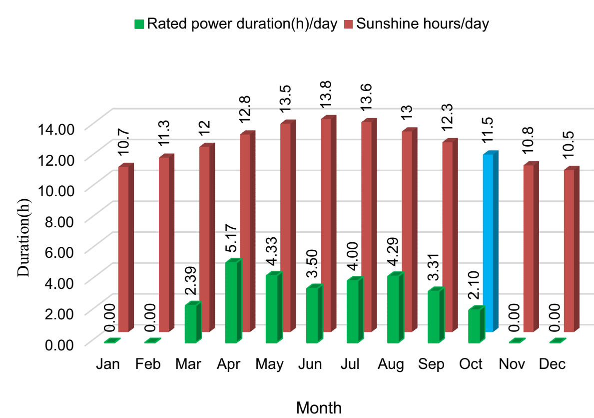

Fig. 6: Operation duration (hours) at rated power of 3 Hp - 3.0 kWp solar system on a bright day for different months against the available sunshine hours

CONCLUSION

The major part India receives solar irradiance below 0.7 kW/m2; therefore, for a good irrigation efficiency and good coverage area per day the size of operating solar array is needs to be revised for potential benefit of solar pumps.

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